Feijóo, Claudio; Gómez-Barroso, José Luis; Ramos, Sergio

Conference Paper

Implications of data-intensive applications for next generation mobile networks

20th ITS Biennial Conference, Rio de Janeiro, Brazil, 30 Nov. - 03 Dec. 2014: The Net and the Internet - Emerging Markets and Policies

Provided in Cooperation with:
International Telecommunications Society (ITS)

IMPLICATIONS OF DATA-INTENSIVE APPLICATIONS FOR NEXT GENERATION MOBILE NETWORKS

Claudio FEIJÓO [*]

José Luis GÓMEZ-BARROSO [♣]

Sergio RAMOS [♣]

Abstract

Lately, the mobile data market has moved into a growth stage triggered by two facts: affordability of mobile broadband, and availability of data-friendly devices. At this stage, market growth is no longer dependent on push strategies from suppliers; on the contrary, demand is now driving the market. However, it will not be easy for mobile operating companies to cope up with the demand to come in the near future. The infrastructure that is needed to support corresponding demand is far from completion. Operators are forced to make heavy investments to upgrade and expand their networks. To decide how to handle the present and upcoming demand, they need to identify and understand the characteristics of the scenarios they face. This is precisely the aim of this article, which provides figures on the consequences for mobile infrastructures of a generalised mobile media uptake. Data from the Spanish mobile deployment case have been used to arrive at practical figures and illustration of results, but the conclusions are easily extended to other countries and regions.

1. INTRODUCTION

Mobile data has followed voice in the process of fixed-mobile convergence. The mobile Internet is having a similar life cycle to its fixed counterpart. Once technological prerequisites were met mobile data access was turned into a commercial offering, and early adopters rapidly joined. Lately, the market has moved into a growth stage that has been triggered by two facts: affordability of mobile broadband (i.e., diffusion of flat rates), and availability of data-friendly – and again affordable – devices. At this stage, technology, supply, and demand have entered into a virtuous

[*] Universidad Politécnica de Madrid – cfeijoo@cedint.upm.es

[♣] UNED (Universidad Nacional de Educación a Distancia) – jlgomez@cee.uned.es / sramos@cee.uned.es

circle in which market growth is no longer dependent on push strategies from suppliers; on the contrary, demand is now driving the market. Paradoxically, however, it is worth noting that success, if not properly managed, may be fatal to some players in this domain.

Where do the main risks lie? In the satisfaction of the demand. Once having experienced the benefits of mobile data access, users want everything in their mobile devices. This also includes every kind of media, any time, anywhere. Substitution effects between mobile and fixed Internet are already in place (Humphreys, Von Pape, & Karnowski, 2013). Moreover, in a growing number of situations, mobile services generate superior value-in-use for customers and will be – and already are in many cases – preferred to fixed services (Gummerus & Pihlström, 2011). Whatever the blend of these effects, one conclusion is clear: it will not be easy for mobile operating companies to cope with the demand to come in the near future. The infrastructure that is needed to support such an 'unleashed beast' scenario – a ubiquitous deployment of Next Generation Mobile Networks (NGMN) – is far from completion. Companies are forced to make heavy investments to upgrade and expand their networks, which then squeezes profits, as the evolution of income is not parallel to that of demand. On the other hand, these companies simply cannot refuse to take up the challenge. To decide how to handle the present and upcoming demand, they need to identify and understand the characteristics of the scenarios they face and will be facing. This is precisely the goal of this paper, which attempts to provide figures on the consequences for NGMN of a generalised mobile media uptake.

The paper is structured as follows. Next section collects information about the expected evolution of different mobile services in the coming years. The third section translates those expectations into service requirements for NGMN. In order to do this, two steps need to be performed: a forecast of the broadband demand from mobile device users, and an analysis of prospective scenarios regarding the evolution of technical parameters that define services. Finally, the paper closes with a discussion on the feasibility and the techno-economic implications for the deployment of NGMN. Data from the Spanish mobile broadband deployment case have been used to arrive at practical figures and illustration of results, but the conclusions are easily extended to other countries and regions.

2. A PROSPECTIVE OVERVIEW OF MOBILE MEDIA SERVICES

The study of the evolution of user demands in mobile media requires some previous categorisation, which classically can be produced from a content and applications perspective (Feijóo, Maghiros, Abadie, & Gómez-Barroso, 2009). However, for this paper it has been preferred to use a service perspective that, although less granular, allows for a much simpler translation into technical requirements.

For each service, overall trends have been highlighted and completed with specific data on usage in Spain, or similar countries where global data were not available. Note that industry sources typically suffer from lack of homogeneity in terms of geographical coverage and the range of years covered. They are also generally obscure about the assumptions made for some of the calculations, and often overly optimistic about the future evolution of the industry. In spite of these considerable drawbacks, though, they offer a unique insight into the industry's knowledge of the demand trends; therefore, subject to the appropriate criticism, they will be used in this section.

Voice and messaging

The shift of users towards mobile data is slowly eroding the relevance of voice and message services, as telephony is substituted by voice-over-IP (VoIP), short text messaging by instant messaging (IM), and diverse types of over-the-top (OTT) services. In spite of this, traditional voice and messaging are still typically forecast to grow modestly in the short to mid term. For instance, Telecomspace (2012) suggests that this market will show a 3% increase in data traffic until 2017, although some other sources suggest a small decline in the amount of traffic over the longer term (UMTS Forum, 2011). In 2012, just 5% of the total mobile traffic originated from voice communications in Europe, with this figure rapidly declining to a marginal rate of the total traffic (Ericsson, 2012). Only less developed countries will show, of the total traffic, a relatively larger proportion dedicated to voice for a longer period. Within this context, mobile VoIP is thought to substitute considerably for conventional voice, with an annual growth of 36% predicted up until 2016 (Cisco, 2012).

Short text messaging (SMS) will follow a similar path to voice, according to industry expectations. It will grow about 3% in the 2016 horizon, with a declining contribution to total traffic (Cisco, 2012) as consumers increase their use of IM – from one billion subscribers in 2012 to 1.5 billion in 2016 – currently, they already send double the number of text messages through IM than through SMS (Deloitte, 2014).

Mail is also accessed increasingly via mobile devices. In 2011, just 400 million consumers accessed their email messages via their mobile devices. Prospects are that this number will increase each year by nearly 30%, resulting in a total of 1.4 billion consumers accessing their mail accounts via their mobile devices in 2016 (Cisco, 2012), a number practically coincident with the number of smartphone users in the mid term.

Web access and social networks

After email, web access was initially the most important service for the surge of mobile data usage. Penetration of mobile web access was 34.7% of the total number of smartphone owners in 2011 and grew to 49.6% in 2012, according to a comScore survey in Spain (2011, 2012).

Social network sites (SNS) are also increasingly accessed via mobile devices. In October 2012, Facebook, the leading social network, reached a user base of 1 billion, of which 600 million users accessed the service via mobile smartphones. In concordance, Cisco (2012) predicts an increase in mobile users of social media, from 679 million users in 2011 to 2.4 billion users in 2016.

From an exclusive technical perspective, these two services are not expected to demand a sustained data rate higher than 1 Mbps in the period considered up until 2020. The possible influence of video is considered separately in the next section.

Audio / Video

The most relevant driver for growth in mobile data is video. Industry analysts (Cisco, 2012) expect that over 70% of all mobile data traffic will be generated by video content in 2016, compared to about 50% in 2012. The Ericsson forecast portrays a more restrained scenario, with video accounting for more than 50% of global mobile traffic but only by 2019 (Ericsson, 2014b), yet with a 55% annual growth rate. With regard to the number of consumers, penetration of the usage of video through smartphones was 32.6% in 2011 and increased to 38.1% in 2012, according to a comScore survey in Spain (2011, 2012). Moving on to the amount of time users spend viewing visual content on mobile devices, it was estimated to be about 10 minutes on average in 2012 (Ofcom, 2012). This includes mostly video from Internet portals and television adapted to mobile media. However, this figure is expected to grow considerably in future, as an increasing number of applications will use some sort of video aspect in their services. Videoconferencing has been cited frequently as a major example (Cisco, 2012), but past failures in predictions do not seem to have been taken fully into consideration. Finally, audiovisual quality is expected to grow dramatically in the next years, with enhancements such as high-definition, 3D, and beyond.

Gaming

According to experts' predictions (De Prato, Feijóo, Nepelski, Bogdanowicz, & Simon, 2010), games will increasingly be played with mobile devices and from the cloud – online gaming. They will also use increasingly more advanced graphics and controls, going from normal definition to high definition and ultimately 3D graphics, and including augmented reality elements (Feijóo, Gómez-Barroso, Aguado, & Ramos, 2012). In fact, a survey from Information Solutions (2011), with both UK and US online panellists, showed that when asked to identify which gaming-enabled device they played games on most often, 44% cited their phones, ahead of videogame consoles (21%) and computers (30%). Also, smartphone owners were by far the most avid mobile gamers: 93% of smartphone owners said that they played at least once each week, and 45% played daily. Regarding global mobile gaming market prospects, the industry expects (Feijóo, 2012) that gaming on this platform will double its value in the period up until 2015, with optimistic estimations for CAGR ranging from 8 to 25%.

From a technical perspective, online gaming is the most demanding type, as gamers must interact on a common visual scenario. This scenario can be locally generated while using some data from a shared server, or it can be streamed over to the mobile device. In the second case, more data rate demanding than the first, it would be equivalent to a video channel with resolution according to game features.

eServices

eServices are an ample and not very well-defined category that includes a range of services, from eCommerce and ePayments to eHealth and eGov. The mobile versions of eServices are usually introduced with an 'm' to distinguish them from their general online counterparts, for instance, mCommerce, mPayments (or mBanking, a wider concept), mHealth, and mGov.

Regarding mCommerce, industry sources (Branding Brand) suggest that in 2014 half of all online shop visits will be carried out via smartphones, and in 2015 this proportion will reach 60%. Along the same lines, in 2015 consumers will spend a total of US$ B10 to 25 in sales via mobile devices (Forrester, Coda Research, ABI Research), at least a fourfold increase compared to mobile consumer expenditure in 2012.

mPayments are expected to double from 2012 to 2016 (Gartner, 2012), with near field communication (NFC) technologies taking an increasingly relevant role (IE Market Research, 2011). In 2012, most mobile payments (about 75%) were carried out via SMS. Using the NFC technology, the mobile device interacts with a receiving device nearby to fulfil the payment, therefore fucntioning as a digital wallet. NFC will be enabled by mobile devices, adding up this functionality to 200 million units in 2015, according to Yankee Group (2011).

mBanking is already a major success in many developing countries, where mobile devices and mobile operators are commonplace and relatively reliable compared to other institutions. Market analysts (IE Market Research, Gartner, Trueaxis) agree on their increasing relevant role globally, with total predicted value of transactions amounting to US$ 900B in 2015.

mHealth has been defined as the way 'to improve individuals' health and well-being by continuously monitoring their status, rapidly diagnosing medical conditions, recognising behaviours, and delivering just-in-time interventions, all in the user's natural mobile environment' (Kumar, Nilsen, Pavel, & Srivastava, 2013). It is therefore a multifaceted service. For instance, already the use of mobile devices by physicians, both to view patient information and to access non-protected health information, is widespread and has grown 15% in 2012 compared to 2011. Healthcare organisations are also increasingly providing patients/consumers with access to mobile devices to promote healthcare, a practice that has seen a 6% growth from 2011 to 2012. Remote patient monitoring devices that are connected to healthcare organisations are also expected to experience considerable growth, although from a purely mobile perspective the most interesting service is personal (biometric) monitoring. This is a category of applications that has grown exponentially in the last years, and includes sports, wellness, and lifestyle utilities.

mGov refers to the use of digital online public services through a mobile device. Until recently, it was simply an alternative means of access to eGovernment services. However, mGov has evolved and now includes the provision of public services that only make sense from a mobile device; real-time information about public transport is a paradigmatic example. According to main experts (Misuraca, Broster, & Centeno, 2011), every scenario of the future eGovernment encompasses mobile technologies that allow bridging real-time mass collaboration tools with sensors, decision-support systems, and cloud computing algorithms (see below) for processing data and performing statistical simulation and analysis.

From a technical perspective, most of the mServices are not very demanding in terms of broadband – with the exception of some mHealth and mass-collaboration mGov solutions – but almost all require reliability and security in data transmission.

Cloud Computing

Cloud computing, the ability to remotely process information, is offered in several flavours: software-as-a-service (SaaS), platform (PaaS), or infrastructure (IaaS). SaaS in the mobile domain means that the application runs mainly on some server accessed from the mobile device. This is the most interesting case for mobile media, and in fact, market analyst Forrester Research forecast 80% of revenues to deriver from SaaS. In PaaS the (business) processes are carried out in the server, while IaaS is the mere capacity of processing and storing data.

Cloud computing is a convergent service in the sense of being agnostic to the type of network / device (fixed or mobile) used when accessing it. In fact, all major developers of cloud computing services typically deploy software solutions adapted for both types of systems at the same time. Expectations for cloud computing indicate that by 2016 each household will have 1.2 TB of data stored in the cloud; most of this data will be accessed while on the move or from a tablet device.

Machine to Machine (M2M) and Internet of Things (IoT)

M2M has been cited frequently as the next engine for growth of mobile systems. In fact, according to a summary report from the EIU (2012), in 2020 between 12 to 50 billion machines are expected to be connected with each other, a 12- to 50-fold growth from 2012. This network of devices is usually called the Internet of Things, stressing the fact that it will be fully compatible and accessible from the Internet. Accordingly, the Internet of Things (IoT) is forecast to reach 26 billion installed units by 2020, up from 0.9 billion in 2015.

From a technical perspective, the data requirements of most M2M devices are limited, as transmission is relatively infrequent and only conveys small amounts of data each time. However, the expected number of M2M devices will be very large compared to traditional devices, therefore having an aggregated impact on the network. To this regard, forecasts published by Cisco Systems suggest that by 2017, roughly 5.1% of the total mobile traffic will be M2M-related; at the same time, it will constitute as much as 17% of the global number of mobile connections (Cisco, 2013).

From the perspective of personal consumers, M2M services will translate to a number of applications, based on information provided by sensors and devices surrounding the user and supplying highly valuable context information (Yndurain, Feijóo, Ramos, & Campo, 2010).

Big Data

Big data refers to datasets whose size is beyond the ability of typical database software tools to manage and analyse. In practice, big data is linked to cloud computing – where the data is processed – and to M2M, where most of the data comes from. Therefore, the same comments for both cloud computing and M2M can be made here, that is to say, big data solutions will be agnostic with regard to the type of access – fixed or mobile – while most of the data will originate wirelessly. For a sense of perspective, industry analysts estimate (McKinsey, 2012) that a corporation of 1,000 employees has about 200 TB of stored data, and that the total data stored in companies amounts to some tens of exabytes. Industry forecasts (Cisco, Gartner, McKinsey) put this figure into the hundreds of exabytes in 2016.

Augmented Reality

Augmented reality consists of layers of information attached to physical reality and read through smart devices (Feijóo, Pascu, Misuraca, & Lusoli, 2009). Augmented reality is intertwined with a number of other services previously mentioned, such as gaming and different types of mobile eServices. This new service is also triggering further innovation in new mobile devices, such as smart glasses. Due to the novelty of this service, industry forecasts are limited to expected growth in revenues. For instance, market analyst Juniper Research (2012) forecasts the market to grow from virtually non-existent to M$ 800 in 2014.

3. A BASELINE OF REQUIREMENTS FOR NEXT GENERATION MOBILE NETWORKS

3.1. Scenarios of future demand of mobile users

Unfortunately, the overview of the industry sources of the above section does not provide a coherent metric for the evolution of mobile services in terms of number of users, nor in terms of intensity of usage, nor in the shape of specific technical requirements. Therefore, using the above section as a departing point, it is necessary to build a more nuanced forecast of a baseline for service evolution, to later be completed with some other alternative scenarios (sensitivity analysis) when departing from the baseline.

In practical terms, the final goal is to predict the evolution of the data rate for an average user. This baseline scenario is built from three main ingredients: (i) number of mobile broadband subscribers; (ii) penetration (number of users) and evolution of technical requirements for each of the services; and (iii) combined usage of services. Sub-sections below explain the assumptions and rationale for each of these elements, and Table 1 offers a summary of the main parameters used and the results of the baseline.

Data from Spain have been chosen for the calculations. Spain is interesting as a case study, for two main reasons: (i) it is a representative case for the EU in socio-demographic terms, (ii) as of the end of 2012, it is the market with the highest penetration of smartphones in the EU, and therefore, a worst-case scenario for network design. In any case, the results obtained with regard to the behaviours of the demand are broadly applicable to developed countries.

Forecast of mobile broadband subscribers

The first step in the creation of a baseline for mobile services is the forecast of the evolution of the number of mobile broadband subscribers. The model chosen is the diffusion of innovations based on the logistic curve, linearised to apply ordinary least squares (OLS) in the estimation process, see for instance Cauwels and Sornette (2012) for details on implementation. The model uses an s-shaped curve for the new adopters' cumulative function, which asymptotically approaches a saturation threshold that is typically determined exogenously. In this paper it has been implemented in a two-stage procedure: the forecast of the penetration of mobile technologies suitable for broadband, and the forecast of the evolution of the penetration of smartphones and tablets with broadband capabilities.

The data set used to perform the first part of the calculations has been obtained from Spanish National Regulatory Agency (CMT), using quarterly data on mobile penetration from 2005 to 2011. As the objective of the calculation is a long-term forecast, seasonal adjustments – moving average of order five – are used to smooth fluctuations. According to the predictions in the literature (see for instance Jefferies, 2011), the market saturation for mobile penetration in Spain will be 130 mobile subscriptions per 100 inhabitants. For the second stage of the calculations, yearly market data on the number of smartphones and tablets in Spain have been compiled from several industry sources. These industry sources predict that the market saturation, that is, the number of mobile devices that can access the broadband mobile network, will be 80% of the total market in 2020 (Jefferies, 2011). After the completion of both forecasting processes, the total demand for mobile broadband subscribers is found by directly combining the smartphone market share and the total number of forecasted mobile lines.

The case of M2M has been treated separately, again using CMT data. As the penetration is still very limited, it has been preferred to use an exponential smoothing technique to provide direct estimations of demand. This technique avoids establishing an a priori market penetration limit. The exponential smoothing method uses a series of weights that give more emphasis to the most recent data and decrease their relevance exponentially as they go back in time. Among the several exponential smoothing techniques, the Holt-Winters model has been chosen with non-seasonal exponential trend procedure (Stellwagen, 2012). The rationale is the assumption that M2M growth will increase slightly each year within the period considered.

The case of mobile cloud computing has been also considered separately. Cloud computing has been linked to companies' smartphones, using data from Spain's National Observatory of Telecommunications and the Information Society, ONTSI. Since penetration in this segment is close to the market saturation level, a non-seasonal linear smoothing (Stellwagen, 2012) has been used for the evolution of the market share of companies' mobile subscribers.

Forecast of service evolution

Service evolution is based on two main parameters: number of users of the service under consideration – that is, the percentage of penetration among mobile broadband potential demand – and technical requirements.

Technical requirements for mobile services have been simplified into maximum data rates, in Mbps. This is equivalent to focusing this article exclusively on the capacity of new mobile broadband networks. The other main parameter left out with this assumption is latency, that is, the ability to provide mobile services in real-time without a noticeable time lapse in the interaction with information. Control of this parameter would increase the complexity of the technical discussion, but in the author's opinion, will not change the fundamental implications from the baseline results. Therefore, only those services from previous sections impacting on broadband have been selected for further consideration, namely: web/social networks, audio/video, gaming, cloud computing, M2M, and augmented reality. This same approach is used by ITU (2000) for the analysis of high broadband services.

The forecast of the evolution of the number of users of each service is based again on a simple logistic model that departs from the values collected from different surveys and studies within the mobile industry, as discussed in the previous section. In the cases of cloud computing and augmented reality, there were not enough values to enable the use of any diffusion model, so an average of the forecast growth indicated by industry sources has been used instead.

The forecast of the evolution of the technical requirements for each of the services is based on the discussion in the above section. Where there were no specific values, it has been supposed that mobile requirements are similar to equivalent fixed services with a four year delay, as indicated in Cave and Hatta (2008) or Noam (2011).

Demand results – Combined usage of mobile services

The next step in the model is the consideration of the simultaneous usage of mobile services by mobile users. The simplest approach is used: the peak demand of users is built from adding the data rates required for each of the services, weighted by the penetration of each of them. In this way, penetration of the different services is used as a proxy for level of usage.

As a summary, and based on the industry forecasts discussed in a previous section, the evolution of the baseline along the period considered can be understood as occurring in three stages. The first takes place in 2013-2015, where mobile broadband subscribers enjoy a combination of web and social media in their smartphones; video of standard TV quality, mainly through tablet devices; options to download and upload some content from limited-scope cloud computing services; options to play online games both through tablet and smartphone; there are also some very basic M2M services. The second stage happens from 2016 to 2018 and adds to the above: HDTV in tablets, advanced online games through tablet and smartphone, and usage of simple augmented reality applications. The third stage starts in 2019 and includes ultra HDTV (possibly 3D), as well as more advanced M2M applications and augmented reality.

Table 1. Average data rate per user baseline

Year		2013	2014	2015	2016	2017	2018	2019	2020
Forecast of mobile broadband subscribers									
Mobile broadband subscribers (millions)		58.42	58.85	59.16	59.39	59.56	59.68	59.77	59.83
Smartphone and tablets penetration (% on mobile broadband subscribers)		69.03	73.79	76.59	78.16	79.01	79.47	79.72	79.85
Mobile 4G demand forecast (millions)		40.33	43.43	45.31	46.42	47.06	47.43	47.65	47.78
Mobile 4G demand forecast penetration (% on population)		87.63	94.37	98.45	100.86	102.25	103.06	103.54	103.82
Forecast of mobile service evolution									
Mobile web / social	Penetration (%)	59.26	69.46	78.05	84.76	89.68	93.15	95.51	97.08
	Evolution data rate (Mbps)	1	1	1	1	1	1	1	1
Mobile audio/video	Penetration (%)	40.23	43.33	46.48	49.66	52.84	55.99	59.10	62.14
	Evolution data rate (Mbps)	2	2	4	4	4	4	8	8
Mobile gaming	Penetration (%)	36.35	39.74	43.22	46.77	50.36	53.94	57.48	60.95
	Evolution data rate (Mbps)	1	1	2	2	2	2	4	4
Enterprise mobile broadband	Subscribers (millions)	9.58	9.62	9.65	9.69	9.72	9.76	9.80	9.83
	Penetration (%)	16.40	16.34	16.31	16.31	16.33	16.35	16.39	16.43
Mobile cloud computing (enterprises)	Penetration (%)	31.10	44.79	64.50	92.88	100.00	100.00	100.00	100.00
	Evolution data rate (Mbps)	1	1	1	1	1	1	1	1
M2M	Penetration (%)	7.16	8.04	8.94	9.86	10.8	11.76	12.74	13.75
	Evolution data rate (Mbps)	0.1	0.1	0.2	0.2	0.2	0.2	0.4	0.4
Augmented reality	Penetration (%)	0.32	0.56	1.00	1.78	3.16	5.63	10.01	17.80
	Evolution data rate (Mbps)	0.2	0.2	0.4	0.4	0.4	0.4	1	1
Demand results – Combined usage of services									
Data rate baseline per average user (Mbps)		1.60	1.93	3.58	3.98	4.31	4.59	8.58	9.11

Alternative demand scenarios

Departing from the user demand baseline, it is possible to build alternative scenarios. Table 2 displays a summary of these, including main assumptions and results. Five alternative scenarios have been considered, four of them exploring changes in the assumptions on specific mobile services, and a fifth to account for general economic evolution. The first supposes that video usage in mobile devices demands higher levels of quality. This could be, for instance, due to the usage of pico-projectors in smartphones or tablets. The second alternative scenario relates to cloud computing, and assumes that not only do companies use this service but also subscribers at large, with a four-year delay regarding professional usage. The third sensitivity analysis refers to a much more aggressive uptake of M2M services and a more intensive usage. The fourth scenario is based on a massive success of augmented reality services. The usage of wearable devices, such as glasses, might be an example. The fifth is a grey scenario assuming an economic stagnation that delays both the deployment and adoption of mobile broadband, reaching the baseline objectives of 80% of penetration in 2030 instead of 2020.

Table 2. Mobile user demand alternative scenarios

Year	2013	2014	2015	2016	2017	2018	2019	2020
Scenario video								
Evolution data rate mobile audio/video (Mbps)	2	2	4	4	8	8	16	16
Data rate baseline change (%)	0%	0%	0%	0%	49.63%	49.75%	56.70%	56.37%
Scenario cloud computing								
Penetration mobile cloud computing (%)	7.23	10.42	15.00	21.60	31.10	44.79	64.50	92.88
Data rate baseline change (%)	3.92%	5.04%	4.09%	5.41%	7.30%	9.95%	7.73%	10.53%
Scenario M2M								
Penetration M2M (%)	7.31	8.51	9.91	11.54	13.44	15.65	18.23	21.22
Evolution data rate M2M (Mbps)	0.1	0.25	0.25	0.5	0.5	1	1	2
Data rate baseline change (%)	0.01%	0.64%	0.19%	0.95%	1.07%	2.95%	1.58%	4.19%
Scenario augmented reality								
Penetration augmented reality (%)	0.47	1.02	2.21	4.79	10.38	22.49	48.76	100.00

Data rate baseline change (%)	0.02%	0.04%	0.13%	0.30%	0.68%	1.50%	4.65%	9.32%
Scenario economic stagnation								
Penetration of mobile broadband (%)	66.78	69.77	72.16	74.04	75.50	76.62	77.47	78.11
Data rate baseline change (%)	-3.13%	-5.19%	-5.57%	-5.02%	-4.23%	-3.42%	-2.75%	-2.13%

3.2. Scenario for the supply of Next Generation Mobile Networks

In order to create a baseline for the evolution of technical parameters that define how NGMNs are deployed, a network architecture needs to be designed. This article considers the market winner NGMN technology – Long Term Evolution (LTE) – as the specific choice for the deployment of the infrastructure part of NGMN.

From an engineering point of view, and once the architecture is defined, the actual network design combines the information from the previous section: the distribution of data traffic per user, the quality of service (QoS), the technical state of the art (spectral efficiency), and policy decisions – basically the frequency of operation of the network and the amount of spectrum bandwidth allocated to the operator. From these four basic parameters it is possible to estimate the average number of users per coverage cell in the mobile network. This paper stops at this point, as this is considered enough to understand the impact of data rates per user, QoS, and diverse technical features and policy decisions. Beyond these initial calculations, the full design of the network would carry on using the specific socio-demographic characteristics of the geographical area aimed at for coverage, establishing the number and location of base stations and other equipment, and from here, calculating figures on investments and operating expenses.

Data rates per user are specified in terms of the quality of service (QoS), expressed in terms of the period of time that users are guaranteed a given data rate ,or alternatively, in terms of the number of users that can be served simultaneously at a given data rate. The QoS is arguably the design parameter that most affects the deployment of a network. In the model, the initial data rate in the period examined per subscriber is set at 1 Mbps. This reference value meets the needs for data applications with higher resource demands, as of 2013 (Radio, Ying, Tatipamula, & Madisetti, 2012). From here, it has been supposed that it will slowly evolve over time towards a similar pattern to that of fixed networks (see Table 3).

The spectral efficiency determines the capacity of each unit of frequency in the allocated bandwidth (see below) to transmit at a specific data rate, and is measured in bits per second per

Hertz. A typical peak value for the spectral efficiency in LTE is 15 bps/Hz (IDATE, 2012), although average values are a third of this value (Raychaudhuri & Mandayam, 2012). The spectral efficiency depends in turn on technology and vendor-dependent parameters, such as the number of sectors and the number of channels for data transmission that are available at a given base station. The numbers of channels and sectors depend on the antenna configurations at the base stations. The model considers a typical LTE configuration, consisting of 3 sectors (each covering a 120º angle) and a 2x2 or 4x4 MIMO channel configuration.

The spectrum bandwidth and the frequency of operation allocated to the operator influence both the coverage and the total throughput of the cell: the higher the bandwidth, the higher the throughput of the base station; and the lower the frequency of operation, the greater the coverage. In fact, the cell coverage is delimited by the lesser of these two components. The first component is the maximum number of users per cell that complies with QoS requirements. This limitation varies inversely with the adoption rate and the population density. The second factor is based on signal transmission losses; beyond a certain distance, the signal is compromised and contains excessive error. The theoretical maximum coverage radius for mobile communications at low frequencies would reach up to 50 km (Astely et al., 2009; Furuskar, Jing, Blomgren, & Skillermark, 2011). However, this value diminishes to just a few km in areas of high building clustering or complex orography, where the combination of diffraction and multipath interference significantly increases signal losses and errors. The first limiting component, QoS, usually occurs in high (urban) and medium (suburban) population density zones, while the second limiting factor is typical of low population (rural) density zones. For these reasons, lower operation frequencies (such as those resulting from the digital dividend) do not necessarily increase network coverage if QoS is the limiting factor. In the model, the bandwidth allocation is 20 MHz, which is currently the typical value for commercial LTE operation (IDATE, 2012). Finally, only a part of the total spectrum bandwidth available is usable, since it is necessary to dedicate part of it to transmit error correction codes and control channels. A typical value of the effective bandwidth is 60% of the total (Mogensen et al., 2007), a value not expected to change over time within the considered period. To summarise in the baseline developed in this paper (see Table 3), the size of the cell due to limitations in QoS is presented for five different types of areas: extreme urban, urban, suburban, rural, and extreme rural.

As a final remark, it should be noted that this article does not consider technical improvements that are *not* expected to be launched massively before 2020.

3.3. Overall results – A baseline of service requirements for NGMN

The first part of Table 3 assumes the average data rate per user obtained in sub-section 3.1. The second part presents a summary of the evolution of the technical parameters, as discussed in the previous sub-section. The result of their combination, in terms of a baseline for base station throughput and for the number of subscribers served within one cell, is presented at the bottom of Table 3.

Table 3. Service requirements baseline

Year	2013	2014	2015	2016	2017	2018	2019	2020
Evolution of demand								
Guaranteed data rate baseline required per average user (Mbps)	1.60	1.93	3.58	3.98	4.31	4.59	8.58	9.11
Evolution of technical features								
QoS (% of data rate available over time)	2	2	5	5	10	10	20	20
Bandwidth allocated to the operator (MHz)	20	20	20	40	40	40	40	60
Spectral efficiency (b/s/Hz)	2	2	3	3	4	4	5	5
Base station –MIMO configuration	3 sectors 2x2 MIMO	3 sectors 2x2 MIMO	3 sectors 4x4 MIMO	3 sectors 4x4 MIMO	3 sectors 4x4 MIMO	3 sectors 4x4 MIMO	3 sectors 8x8 MIMO	3 sectors 8x8 MIMO
Base station max. throughput	240	240	720	1440	1920	1920	4800	7200
Service requirements for Next Generation Mobile Networks								
Max. number of users per cell	4500	3731	2413	4342	2673	2510	1678	2371
Radius of cell for ext. urban areas (5000 inh/km^2) in km	0.57	0.50	0.40	0.52	0.41	0.39	0.32	0.38
Radius of cell for urban areas (1000 inh/km^2) in km	1.28	1.12	0.88	1.17	0.91	0.88	0.72	0.85
Radius of cell for suburban areas (500 inh/km^2) in km	1.81	1.59	1.25	1.66	1.29	1.25	1.02	1.21
Radius of cell for rural areas (50 inh/km^2) in km	5.72	5.02	3.95	5.23	4.08	3.94	3.21	3.81
Radius of cell for ext. rural areas (10 inh/km^2) in km	12.79	11.22	8.83	11.71	9.12	8.80	7.18	8.53

Sensitivity analysis

As in the case of mobile usage, it is worthy to consider some alternative scenarios and their impact on the amount of users that can be served within a cell. Table 2 displays a summary of these, including main assumptions and results. The first scenario explores the lack of improvements of QoS, which are basically considered to stay at current levels with a slight improvement at the second part of the period. The second scenario is exactly the opposite, examining the influence of fully anticipating consumers' demands for mobile media and thus guaranteeing data rates at all times. The third displays a situation where there are no improvements in bandwidth allocated to operators. The final scenario summarises the effect of the lack of technical improvements through the spectral efficiency parameter, which is supposed to be enhanced at a much slower pace than in the baseline.

Table 4. Technical requirements alternative scenarios

Year	2013	2014	2015	2016	2017	2018	2019	2020
Scenario limited QoS								
Evolution of QoS (%)	1	1	1	1	2	2	2	2
Max. number of users per cell baseline change (%)	100%	100%	400%	400%	400%	400%	900%	900%
Scenario max. QoS								
Evolution of QoS (%)	100	100	100	100	100	100	100	100
Max. number of users per cell baseline change (%)	-98%	-98%	-95%	-95%	-90%	-90%	-80%	-80%
Scenario limited bandwidth								
Bandwidth allocated to operators (MHz)	20	20	20	20	20	20	20	20
Max. number of users per cell baseline change (%)	0%	0%	0%	-50%	-50%	-50%	-50%	-66.6%
Scenario technological stagnation								
Spectral efficiency (b/s/Hz)	1.4	1.4	1.4	2	2	2	2	2
Max. number of users per cell baseline change (%)	-30%	-30%	-33.3%	-33.3%	-50%	-50%	-60%	-60%

4. DISCUSSION OF RESULTS

The first and most important element for discussion is the data rates obtained in the baseline. The figures show an average annual growth of 31% in the period considered. This is slightly more conservative than those of existing industry forecasts. In fact, according to industry analysts, mobile data traffic is expected to grow at rates of more than 50% until 2020, increasing from 1.3 EB/month in 2012 to approximately 40 EB/month (Jefferies, 2011). Also, according to Ericsson (2014a), mobile data traffic already exceeded 2 EB/month at the end of 2013, with a growth of 70% year-on-year.

The data rates in the baseline are relatively similar to those apparently available for mobile broadband consumers in diverse practical situations. In a survey of 77 mobile operators in 3Q 2013, it was found that average connection speeds ranged from 9.5 Mb/s to just 0.6 Mb/s – with the mean value of the distribution in the range of 2 to 3 Mb/s – while average peak connection speeds ranged from 49.8 Mb/s down to 2.4 Mb/s (Akamai, 2013). Values in the baseline are again slightly more conservative than those of existing industry forecasts.

In any case, QoS is precisely the parameter that explains the differences between guaranteed (minimum) speeds and other situations. According to the baseline, and taking for instance the 2014 values, there would be only a 2% guarantee of satisfaction of the expectations of mobile media consumers at the peak (maximum congestion) time, or equivalently, only 1 in 50 customers would have their expectations fulfilled at that moment. Even supposing that the above surveys represent the real situation and maintain the rest of the baseline assumptions, it would mean a 2.5% probability of achieving the maximum data rate, or on average, satisfying 1 in 40 mobile media consumers at peak time.

In fact, lack of QoS is arguably the main source of frustration for mobile media consumers. Considering again 2014, and assuming that investments are proportional to the number of users per cell, fully satisfying users' expectations at any time would mean multiplying the level of investments by 40 (for the surveys above) or by 50 (for the baseline scenario). If a more realistic situation with a QoS of 10% is considered, it would imply quadruple investments (surveys data) or quintuple investments (baseline data). This same idea is reflected in the evolution of the investments, simply to keep pace with users expectations while increasing QoS according to the baseline assumptions. In this case, it would be necessary to increase investments by a factor of about two from 2014 to 2020, in those areas where QoS is the limiting factor (at least in urban and suburban areas), an indication of the formidable challenge confronted by mobile operators, as even with the technology deployed, it would be necessary to keep investing in already covered areas to keep pace with increasing user demands, as discussed below. In fact, it is rather unclear how this considerable effort on the side of mobile operators would be achieved in a relatively flat or slightly declining mobile. An easy and tempting solution would be to keep QoS at existing levels. This would save investments; however, although the price to be paid in terms of consumers' dissatisfaction, decrease of the overall utility, and lack of innovations that could make use of a better guarantee in data rates is difficult to evaluate, it nevertheless appears to be considerably negative.

The combined effect of the increase of data rates and QoS results in a large reduction of the number of subscribers served by a single coverage cell – it decreases on average by a factor of 2 along the considered period. Apart from the direct effects on investments in the number of base stations, it also implies that a much denser pattern of base station should be deployed. For instance, in urban areas, the size of the radius of a coverage cell would go down to some hundreds of metres from its current radius of 2 to 3 km. These base stations, in addition, would manage a much larger amount of data traffic – the throughput – and therefore, new fibre cabling would be needed to connect new sites to the backbone network in order to transport data further. These fibres are not deployed yet in general and thus, in a relative contradiction, mobile operators will be the most avid users – and/or deployers – of fibre in the next years. As an illustrative example, the number of sites required in a metropolis such as Madrid municipality (average population density of 5300 inh/km^2) would increase from about 250 in 2012 to more than 1300 in 2020.

QoS will also be, increasingly, the limiting factor in NGMN deployments. For instance, in rural areas, the size of the cell would go down from about 6 km in 2013 to about 4 km in 2020. Therefore, in spite of acknowledging the role of mobile broadband as the only economically feasible solution in terms of NGN deployment in rural regions, these results imply that considerable investments would be needed in the deployment of new cells, in addition to the replacement of existing sites with new 4G technologies. These results also entail that lower frequencies of operation of mobile networks would reduce investments only for a limited number of years – before QoS becomes the limiting factor – in rural areas with low density of population. Therefore, in the long term, lower frequencies of operation of mobile networks would only be essential for better coverage indoors and in areas of high clustering of buildings – therefore saving in equipment to fill coverage gaps – and in rural areas with extremely low density of population.

Policy decisions and technical developments also have a deep impact on the level of investments required, contributing decisively to the potential profitability of NGMN and to the satisfaction of users' demands. For instance, not enjoying additional spectrum at all in 2020 would imply an increase of investments of 300% with regard to the baseline situation, or, translated in terms of QoS, a reduction from 20% to a 7% chance of satisfying consumers. Therefore, there is an obvious and critical role for spectrum regulation in contributing to the development of mobile media beyond the current standards. A very similar situation takes place with technical developments. The improvements in spectral efficiency in 2020 would translate to investment savings of 250%, compared with a situation where these improvements do not happen at the baseline pace. Again, this could be translated as a decrease of QoS to just 8%, to compensate for the difference in network investments.

From the perspective of consumer behaviour on mobile media, video appears to be the most relevant factor. For instance, if the alternative scenario where video requires a much higher quality in 2020 is considered, it would translate into a 56% increase of investments. This would notoriously enlarge the existing gap between the growth in mobile data traffic – mostly driven by video – and the revenues that mobile operators extract from it, thus increasing, in turn, the pressure to either slow the pace of investments in access network capacity, create tariffs that adapt better to the use of resources from the network, arrive at agreements for sharing revenues with OTT providers, or any combination of them. None of these potential remedies is void of formidable challenges, and to date there is nothing like a unified approach to the issue.

Continuing with possible disruptions in user adoption of mobile services, the next most broadband-demanding services appear to be cloud computing and variations in the adoption of augmented reality. As indicated in the alternative scenarios, both would need about a 10% increase in network investments, should they follow these other roadmaps of adoption.

Finally, it should be noted that the baseline is relatively robust to changes in the assumptions on the adoption of mobile broadband in general. This is due to the already high levels of penetration of mobile technologies in general, and signals that only catastrophic scenarios would depart significantly from the baseline in this particular aspect. They also show that the fundamental driver for mobile media adoption is already present in the period considered: a mobile broadband subscriber armed with smartphones and tablets, eager to obtain ubiquitous access to new and appealing services and applications.

5. CONCLUSIONS

In fostering a discussion about the mobile media future and its implications for NGMN, this article has introduced a number of scenarios for the evolution of mobile services and networks. The resulting baseline hints at both technological, strategic and policy enhancements that could be implemented to increase the chances of further developments in mobile media. The baseline can also serve as a benchmark for other scenarios not considered in the paper, such as alternative network architectures, or convergence with fixed networks. Note also that the authors are well aware of the high number of assumptions required to build even such a rough baseline for the evolution of mobile media and networks; therefore, great care has been used to specify each of the assumptions in order to facilitate ease of replicability, reviews and modifications.

Reading the results collectively, some general panorama for mobile media can be depicted. Its most distinctive feature is that, with the arrival of NGMN, the mobile industry's traditional virtuous cycle of investment, innovation, and adoption of services has been broken, substituted with a cycle that runs in the opposite direction. Now it is the innovation and adoption of services by users which require investments from mobile operators, although these will not necessarily accrue to facilitate an increase in operators' revenues. Both forces will remain strong during the period considered, fuelled by mobile media's notorious utility for mobile broadband consumers and their established habits. Therefore, the pressure on operators, to conduct the required investments and to increase both data rates and QoS, will only intensify. A part of this pressure will be transferred to the search for business models linked more directly with the use of network resources, either by consumers or by any other party. Another part of this pressure would be translated to policymakers, as, in a particular spectrum, the bandwidth would considerably decrease the investments required or, alternatively, increase the data rates and/or QoS offered to mobile users.

REFERENCES

Akamai. (2013). *The state of the Internet, 3rd quarter, 2013 report.* Retrieved from http://www.akamai.com/dl/akamai/akamai-soti-q313.pdf?WT.mc_id=soti_Q313

Cauwels, P., & Sornette, D. (2012). Quis pendit ipsa pretia: Facebook valuation and diagnostic of a bubble based on nonlinear demographic dynamics. *Journal of Portfolio Management*, *38*(2), 56–66. doi:10.3905/jpm.2012.38.2.056

Cave, M., & Hatta, K. (2008). Universal service obligations and spectrum policy. *Info*, *10*(5-6), 59–69.

Cisco. (2012). Cisco visual networking index: Service adoption forecast 2011-2016.

Cisco. (2013). Cisco visual networking index: Global mobile data.

Coomonte, R., Feijóo, C., Ramos, S., & Gómez-Barroso, J. L. (2013). How much energy will your NGN consume? A model for energy consumption in next generation access networks: The case of Spain. *Telecommunications Policy*, *37*(10), 981–1003. doi:10.1016/j.telpol.2013.09.002

De Prato, G., Feijóo, C., Nepelski, D., Bogdanowicz, M., & Simon, J. P. (2010). Born digital / grown digital: Assessing the future competitiveness of the EU video games software industry. *JRC Scientific and Technical Reports*. Luxembourg: Publication Office of the European Union: Institute for Prospective Technological Studies - Joint Research Centre - European Commission.

Economist Intelligence Unit. (2012). Rise of the machines: Moving from hype to reality in the burgeoning market for machine-to-machine communication.

Ericsson. (2012). *Traffic and market report: On the pulse of the networked society.* Stockholm.

Ericsson. (2014a). *Ericsson mobility report.* Updated Feb 2014.

Ericsson. (2014b). *Media Vision 2020: A vision of the Television Future.* Retrieved from http://www.ericsson.com/televisionary/static/pdf/MediaVision-Brochure-RevA.pdf

Feijóo, C. (2012). An exploration of the mobile gaming ecosystem from developers' perspective. In P. Zackariasson (Ed.), *The video game industry: Formation, present state, and future* (pp. 76–95). New York & London: Routledge.

Feijóo, C., Gómez-Barroso, J. L., Aguado, J. M., & Ramos, S. (2012). Mobile gaming: Industry challenges and policy implications. *Telecommunications Policy*, *36*, 212–221. doi:10.1016/j.telpol.2011.12.004

Feijóo, C., & Gómez-Barroso, J. L. (2013). El despliegue de redes de acceso ultrarrápidas: Un análisis prospectivo de los límites de mercado. *Papeles de Economía Española*, (136), 116–129.

Feijóo, C., Gómez-Barroso, J. L., & Ramos, S. (2011). *An analysis of Next Generation Access Network deployment in rural areas.* 50th FITCE Congress, Palermo, Italy.

Feijóo, C., Maghiros, I., Abadie, F., & Gómez-Barroso, J. L. (2009). Exploring a heterogeneous and fragmented digital ecosystem: Mobile content. *Telematics & Informatics*, *26*(3), 282–292. doi:doi:10.1016/j.tele.2008.11.009

Feijóo, C., Pascu, C., Misuraca, G., & Lusoli, W. (2009). The next paradigm shift in the mobile ecosystem: Mobile social computing and the increasing relevance of users. *Communications & Strategies*, (75), 57–78.

Gartner. (2012). *Forecast: Mobile payment, worldwide, 2009-2016.*

Gummerus, J., & Pihlström, M. (2011). Context and mobile services' value-in-use. *Journal of Retailing and Consumer Services*, *18*(6), 521–533.

Humphreys, L., Von Pape, T., & Karnowski, V. (2013). Evolving mobile media: Uses and conceptualizations of the mobile Internet. *Journal of Computer-Mediated Communication*, *18*(4), 491–507.

ITU. (2000). Recommendation ITU-R M.1079-2. *Performance and quality of service requirements for International Mobile Telecommunications-2000 (IMT-2000) access networks.*

Jefferies. (2011). *Mobility 2020: How an increasingly mobile world will transform TMT business models over the coming decade*.

Kumar, S., Nilsen, W., Pavel, M., & Srivastava, M. (2013). Mobile health: Revolutionizing healthcare through transdisciplinary research. *Computer*, *46*(1), 28–35.

Misuraca, G., Broster, D., & Centeno, C. (2011). Digital Europe 2030: Designing scenarios for ICT in future governance and policy making. *Government Information Quarterly*, (10). doi:10.1016/j.giq.2011.08.006

Mogensen, P., Na, W., Kovács, I. Z., Frederiksen, F., Pokhariyal, A., Pedersen, K. I., … Kuusela, M. (2007). LTE capacity compared to the Shannon bound. In *Vehicular Technology Conference, 2007. VTC2007* (pp. 1234–1238).

Noam, E. M. (2011). Let them eat cellphones: Why mobile wireless is no solution for broadband. *Journal of Information Policy*, *1*, 470–485. Retrieved from http://jip.vmhost.psu.edu/ojs/index.php/jip/article/view/64/43

Stellwagen, Eric. (2012). Exponential smoothing: The workhorse of business forecasting. *Foresight,* (Fall), 23–28.

Telecomspace. (2012). SMS will remain more popular than mobile messaging apps over next five years. Retrieved from http://www.telecomspace.com/content/sms-will-remain-more-popular-than-mobile-messaging-apps-over-next-five-years-informa

UMTS Forum. (2011). *Mobile traffic forecasts: 2010-2020 report.* UMTS Forum Report 44.

Yndurain, E., Feijóo, C., Ramos, S., & Campo, C. (2010). Context-aware mobile applications design: Implications and challenges for a new industry. *Journal of the International Telecommunications Professional*, *4*(4), 16–28.